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13. ABSTRACT *(Maximum 200 words)*
BACKGROUND: Establishing a patent airway coninues to be a priority whether performing basic or advanced combat trauma life support. Although many airway devices may be used to this purpose, upper airway clearance first necessitates removal of vomitus, blood or other secretions. Suction units on the market were identified and evaluated for potential far forward use in the Special Operations environment.
METHODS: Literature review pertaining to compact suction devices was performed. Stand-alone suction systems were identified. Suction devices with potential far forward application were obtained and evaluated in the laboratory at the Walter Reed Army Institute of Research, Division of Surgery. Those systems still felt to have promise were evaluated by 18 Delta Special Operations corpsmen.
RESULTS: A number of suction pumps were identified. These were narrowed down to two battery-powered pumps, the Vac-Pak II (Impact) and Compact Suction Unit (Laerdal), one foot-powered pump, the Twin Pump (Ambu), and two hand-powered models, the Res-Q-Vac (Repro-Med) and V-Vac (Laerdal). An additional hand-powered model was later added (Emergency Aspirator, Vitalograph). Small, compact, lightweight devices are desired. The V-Vac and Emergency Aspirator suction pumps were the most appropriate for far forward use.
CONCLUSIONS: No available suction device is ideal for the far forward Special Operations environment. The V-Vac and Emergency Aspirator appear to be the best choices, however, they are slightly large. Although some 18Deltas carry these systems, many use bulb syringes, which provided poor suction in our study. A 60cc plunger syringe can provide suction, but shape, capacity and need for two hands are limiting. When extremely limited space requires carrying a syringe, a Toomey plunger-type, combined with a soft suction catheter should be employed. Further development of a suction pump system is necessary before a more ideal product, for Special Operations, is available.

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FOREWORD

This research was carried out under funding line 1160407BB. The project was supported by the Biomedical Initiative Steering Committee, United States Special Operations Command. This group coordinates a number of research, as well as research and development, projects designed to enhance the abilities of Special Operations medics, corpsmen and pararescuemen to care for casualties in the Special Operations environment. The following research presented was performed through Combat Trauma Research, Department of Resuscitative Medicine at the Walter Reed Army Institute of Research, Washington, DC.

Naval Special Warfare Group One Medical, Coronado, CA, made this evaluation possible by allowing the author's participation in the Advance Battlefield Trauma course. Their efforts and the efforts of the evaluating Special Operations corpsmen are greatly appreciated.

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Evaluation of Suction Pumps for Far Forward Application

Background

Establishing a patent airway remains a major priority from basic to advanced combat trauma life support. Although airway devices may be used to accomplish this, often upper airway clearance first requires removal of vomitus, blood or other secretions. For this reason we were asked to identify and evaluate available suction units for potential far forward use by 18 Delta-trained corpsmen/medics in the Special Operations environment.

The goal was to (1) perform a literature review, (2) identify available stand-alone suction systems with potential far forward application, (3) obtain and evaluate those identified units in the laboratory, (4) have those suction devices which still appeared to have promise evaluated by 18 Delta trained, Special Operations medical care providers.

Methods

Literature review was performed to identify available suction devices that had been formally evaluated. Other portable suction systems were identified through catalogue and internet searches. Available units thought to have possible application in the far forward Special Operations setting were purchased. In laboratory assessment included measurements of dimensions, weight and suction power as well as subjective appraisal of durability and simplicity of use. Those suction units still felt to have potential were evaluated by 18 Delta Navy SEAL and Reconnaissance combat corpsmen. Assessment included evaluation of simplicity of design and function (suction of imitation vomitus), followed by completion of a questionnaire regarding perceived durability, positive and negative features, as well as preferences. !8 Delta evaluations focussed on potential use of these devices in the Special Operations environment.

Results

The Literature

Review of the literature revealed one applicable study dealing with evaluation of smaller suction systems: Arnstein FE. A practical evaluation of four human-powered airway aspirators. Anaesthesia. 1996. 51: 63-68. Arnstein used twenty experienced

hospital workers (people who had attended one or more courses on resuscitation) and twenty unexperienced hospital workers (no prior formal resuscitation training) to compare the Emergency Aspirator (Vitalograph), Res-Q-Vac (Repro-Med), V-Vac (Laerdal) and the Maxi-Suction Pump (Ambu) (see below for description of these devices). Performances and preferences of trained and untrained hospital workers were similar. Overall choices for a particular device revealed 16 preferences for the Res-Q-Vac, 15 for the Ambu Maxi-Suction, 7 for the Emergency Aspirator and 2 for the V-Vac. Although this study appeared to be well done, important information regarding out-of-hospital, far forward application, by trained combat care providers, was lacking.

Identifying the Equipment

Ideal pumps for far forward use should be rugged, lightweight, compact, quiet, simple, have minimal moving parts, tracheal adaptors and good suction. These became rough criteria when identifying available systems.

Power for suction can come from several sources: piped vacuum (often used within hospital operating and emergency rooms), electrical (internal battery or external connection) or human power (usually foot or hand pumps). Because external vacuum or electrical sources are not available in the field, these types of devices were excluded. Stand-alone units that contained internal battery power or derived suction from human pumping appeared to be necessary.

A number of electrical or human powered stand-alone units can be seen in any hospital or emergency medical equipment catalogue. The devices were narrowed down, using the above mentioned rough criteria, to two electrical units, one foot-powered unit and three hand-powered units (TABLE 1). The Vac Pak II Ultra-lite (Impact) and Compact Suction Unit (Laerdal) utilize internal batteries. The Ambu Twin Pump is foot-powered, while the Emergency Aspirator (Vitalograph), Res-Q-Vac (Repro-Med) and V-Vac (Laerdal) are powered by hand.

WRAIR Laboratory Evaluations

Laboratory evaluations took place at the Walter Reed Army Institute of Research, Division of Surgery, Combat Trauma Research. Factors assessed included weight, dimensions, volume and vacuum power, as well as subjective assessment regarding simplicity of operation and durability.

When evaluating suction power, a vacuum gauge was connected to the units. Scaling was all converted to mm of Hg. The numbers reported on Table 1 reflect averages of first pull suction as well as maximum suction obtained. Battery powered devices resulted in a gradual rate of rise of pressure without an initial set reading at any particular time. This was related to their constant suction. Foot and hand powered models give an initial vacuum measurement and, if a seal remains, a gradual increase to a maximum volume. Initial first pull measurements would seem to be important as a continuous seal will not always occur in the clinical setting.

The Impact Vac Pak II Ultra-lite (VPII) and Laerdal Compact Suction Unit (CSU) operate using internal rechargeable batteries or external electricity. The CSU (figure 1) was the most compact of the electrical models. Unfortunately, batteries still increase weight and volume. Both units had approximately one liter volume capabilities. The VPII, seen in figure 2, uses a potentially disposable chamber, whereas the CSU collection container must be cleaned after use. Vacuum capabilities were also similar. Each unit sells for approximately $500. Such units, although simple to operate, are complex in internal nature, weighty, have limited power and are not extremely rugged.

The Ambu Twin Pump (TP), photographed in figure 3, operates when foot power is applied. The Ambu Maxi-Suction foot powered pump, evaluated by Arnstein, is larger and heavier than the Twin Pump. Therefore, the TP was assessed in our evaluation. This device, measuring 8 1/8" x 4 1/4" x 4" and approximately 1.1 kg, consists of two chambers over which a gas pedal-like platform rests. The pedal pivots at a point between the two chambers. Pumping creates suction through tubing connected to the chambers. The suctioned material collects within the chambers, limited at 600 cc total. The unit is ideally taken apart and cleaned for subsequent use. Price is approximately $300. The plastic collection chambers could possibly be fractured with rough treatment, although the rest of the unit was rather rugged. Weight and size are significant.

The Vitalograph Emergency Aspirator (EA), seen in figure 4, creates suction when the trigger is pulled toward the handle. A piston moving forward, as a ball valve in the rear of the device closes, leads to vacuum formation in the units rear chamber. This leads to a vacuum in the forward aspirate container and the suction catheter. As a spring returns the trigger on release, a nonreturn valve prevents backward flow of material from the collection chamber down the catheter and the ball valve at the back opens, allowing air and any excess fluid to be ejected out the rear of the unit. A mesh filter within the aspirate container collects larger particles, preventing their interference with the aspirator's vacuum creation. The unit, at 6 3/4" x 3.5" x 6 1/2" and 376 grams, creates

adequate suction. Cleaning of the aspirate container is necessary after use. Although the volume of the chamber is approximately 240 cc, excess overflow liquid can be eliminated out the rear of the unit. When overflow occurs, additional cleaning of the unit is required. The EA, unlike the other hand-powered models, does not have disposable parts other than the attachable catheters. Price is approximately $200. Operational temperatures are reported to be –20 to +50 degrees Celsius. The device, although made of multiple moving parts, did appear to be well built and durable.

Repro-Med's Res-Q-Vac (RSQ) (figure 5) utilizes a concept similar to the EA for generating vacuum with a hand pump. A main, reusable pumping unit is connected to disposable collection chambers with an attached catheter. The volume is limited at approximately 220 cc with no capability for overflow. When more than 130 cc are suctioned, the manufacturer recommends maintaining a vertical position to prevent contamination of the main suction handle. If contamination occurs this way or due to overflow, the manufacturer recommends discarding the whole unit. The RSQ kit sells for approximately $50 as a reusable handle and disposable fluid trap (approximately $40 for the reusable handle). Additional fluid traps are sold for approximately $12. No range of temperature is given regarding operation. This model, like the EA, consists of multiple moving parts, however, the RSQ material appears to be less rugged.

Laerdal's V-Vac (VV) also operates by hand power. However, this device, consists of a simple spring-powered handle and a disposable accordion collection cartridge. Compressing the spring generates vacuum within the now expanding collection chamber. Following release, a valve at the tip of the catheter prevents retrograde flow and a rubber flapper valve on the side of the replacement cartridge allows the escape of air. Although the cartridge capacity is 400cc, excess fluids can be eliminated through this same side valve. A sponge filter prevents spraying of this material. A kit price is approximately $75 for the reusable handle and two disposable collection cartridges (roughly $50 for the reusable handle). Additional collection cartridges can be purchased for around $12 a piece. Recommended operating temperatures are –18 to 45 degrees Celsius. Minimal parts, simplicity, ruggedness and tracheal suction attachments are features of this device. Figure 6 pictures the VV and its attachable tracheal suction catheter

18 Delta Evaluations

The Advanced Battlefield Trauma (ABT) course put on by Naval Special Warfare Group One Medical was utilized to obtain evaluation by 18 Delta medical care providers.

This course involves a first week of classroom, didactic and animal laboratory training in combat trauma life support. These students were given an orientation to the CSU, VV, RSQ and TP. The VPII suction pump was removed from the evaluation due to its large size, weight and noise. At the time of the ABT the EA was obtained, so it was included in the evaluations. Following the ABT, it was necessary to return to the lab to complete the laboratory evaluations of the EA which are reported above and in Table 1. The corpsmen were then allowed to familiarize themselves with the devices.

Containers were filled with simulated vomit made from a mixture of water and soup. The 18 Delta evaluators assessed the different devices, their ability to clear the vomitus, and their potential application for the Special Operations environment. They then completed a questionnaire (Table 2).

The compiled responses to the questionnaire in Table 2 follows. The multiple answers, average of ratings and comments are reported.

Do you presently take a suction device into the field?

All responses were YES. Almost all reported carrying a large syringe of some type – Toomey, 60cc, bulb syringes. Some do report carrying the V-Vac.

Reasons for these responses included – simplicity, no parts to break, cheap, easy, functional, multiple uses, minimal space, light

The 18 Deltas questioned were asked to rate a number of factors related to suction pumps. Each of the factors was rated on a scale from 1 (unimportant) to 10 (very important). The averages are reported.

How important is size?	9.43
How important is weight?	9.57
How important is suction power?	8.43
How important is noise factor?	8.00
How important is electric power?	1.14
How important are tracheal adapters?	7.29

The participants were also asked to rank the above features from 1 (most important criteria) to 6 (least important). This question would force 18 Delta evaluators to but one criteria in front of the other. The averages are reported.

Size	1.0	Suction Power	3.5	Adapters	4.7
Weight	2.0	Noise	3.8	Elect power	6.0

What other factors are important? The following responses are compiled.

Need few adapters – less time to use, less time to loose

Ease of use	Minimal moving parts	Availability
Durability	Cost	

The next question asked the providers which device appeared to meet the above mentioned criteria.

> The V-Vac had the most responses although some still expressed concerns over the size of the device. Reasons included its light weight, quiet action and easy clean usage with unlimited volume. The Emergency Aspirator was listed as was the Res-Q-Vac. Some stated that no devices were appropriate.

The next question asked the providers which device they least liked.

> The Twin Pump was by far the most disliked. Reasons included large size and weight, complicated nature with many parts and its bulkiness. The Res-Q-Vac was listed by one 18 Delta due to its multiple moving parts, potential fragility and limited volume. The Laerdal CSU was said to be too heavy and loud.

Our questionnaire asked the participants to rank the devices from best (1) to worst (4). Please note that at the time the questionnaire was written, we had not yet seen the EA. So that particular device was not listed on the prewritten questionnaire and did not receive a ranking.

Laerdal V-Vac	1.57
Repro Res-Q-Vac	2.00
Laerdal Compact Suction Unit	2.71
Ambu Twin Pump	3.71

Lastly, suggestions for possible modifications were added.

VV	make it 1/2 the size, make it smaller
RSQ	attachments
General	keep it simple

Conclusions

Electrical suction pump systems are inappropriate for man packing. The units evaluated were among the smallest available and yet still too large, too heavy and too noisy. In addition, limited power source is available in the battery packs which also require recharging. The VPII and CSU, which work well in an emergency room or ambulance, are not options for far forward use. The units evaluated could be used on insertion/extraction platforms should space be available. The smaller CSU appears to be the most suitable for this application.

The TP foot powered suction system appears to have no application for the Special Operations environment. This unit is excessively large, heavy and cumbersome to use. The limited volume and need to take apart and clean are additional negatives. The civilian Arnstein study revealed significant preference for the Ambu Maxi-Suction foot pump, even larger and heavier than the TP. The TP was the most disliked of the units evaluated.

Hand powered systems have the most potential for the Special Operations environment. Although a significant number of evaluators in the Arnstein study and one 18 Delta in our study preferred the RSQ, concerns of most evaluators (18 Delta and the author) center around the multiple moving parts and a pump handle which does not appear to be sturdy. A limited capacity, which when reached results in contamination requiring the unit to be discarded, is an additional disadvantage. The EA, although operating on a similar principal to the RSQ with multiple parts, appears to be fairly rugged and can be operated at extremes of temperature. Capacity is not limited, but when overflow occurs, the unit requires additional cleaning. The overflow valve resides in the rear of the device. Although we did not see it, Arnstein reported overflow onto the users from rearward spray. Another potential disadvantage of the EA is its cost of $200 per unit. Size is slightly smaller than the VV. The VV system is very simple, lightweight and rugged, with the ability to operate at extremes of temperature. Overflow is located on the side of the unit, which helps prevent spillage on the user. Most 18 Deltas evaluating the systems chose this device out of those evaluated. The main advantage

relates to simplicity and low cost. The main disadvantage relates to its size (a problem with each of the units tested). The VV is probably the best of the devices when comparing simplicity, suction capability, attachment options, capacity and price. This particular device would be extremely advantageous if it existed in a smaller size.

Note that the preferences of Arnstein's evaluators, looking at the devices from a civilian, in-hospital point of view, differed rather significantly from those of our 18 Deltas. The Special Operations corpsmen most disliked a smaller relative of one of the devices that Arnstein's evaluators most preferred. Another device that a large portion of the civilian providers liked was the RSQ. Concerns over its ability to operate under rugged conditions made this device less preferred by Special Operators. Had such information been applied from their experience to that of the military, inappropriate devices would have been chosen.

No available suction device is ideal for the far forward Special Operations environment. Although the EA and VV appear to be the best of the choices, they still are too large. They represent appropriate choices for insertion/extraction platforms when space on a particular vehicle is limited (when vehicle space is available, the CSU is reasonable). A few Special Operators carry the VV, however the majority report packing a large syringe for suction purposes. In our laboratory evaluations, the 50cc bulb syringe (photographed in figure 7) pulls an average of 59.5 mm Hg, significantly less than any of the units evaluated and largely inadequate. The 60cc Toomey tapered-tip plunger syringe (figure 8) pulled an initial 373.8 mm Hg, up to a maximum of 589.6 mm Hg, but required two hands (not usually necessary with the other devices). Maintenance of a constant seal is also required to obtain this good vacuum. Such vacuum is due to pull on a plunger being applied over the very small cross sectional area of the spout. Unfortunately, even if these have appropriate suction power, due to their shape, they lack the ability to swiftly remove significant vomitus, blood or secretions. A Yankauer-type attachment (pictured in figure 7 with the bulb syringe), available for taper-tipped syringes (like the Toomey), does improve on this, but reduced capacity will require frequent emptying of the syringe. When extremely limited space requires carrying only a syringe for suction, the Toomey with this soft catheter is probably the best option. This does not allow for suction of tracheal contents within the endotracheal tube, although an additional thinner attachment could possibly be devised. Further development of a suction pump system is necessary before a more ideal product, for the Special Operations environment, is available. A simple change in size of the VV to at least half its original size (or preferably smaller) would represent something close to ideal.

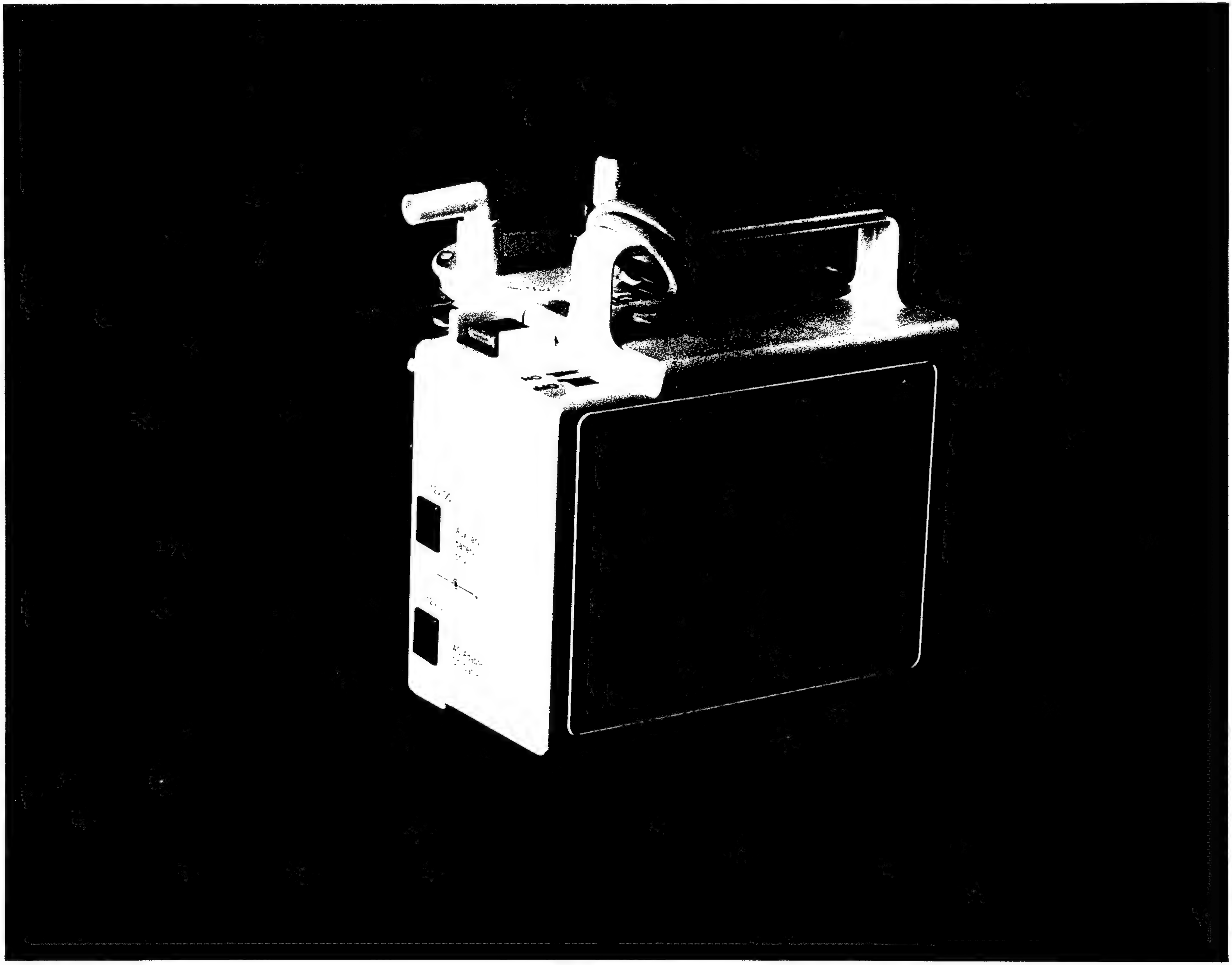

Fig 1

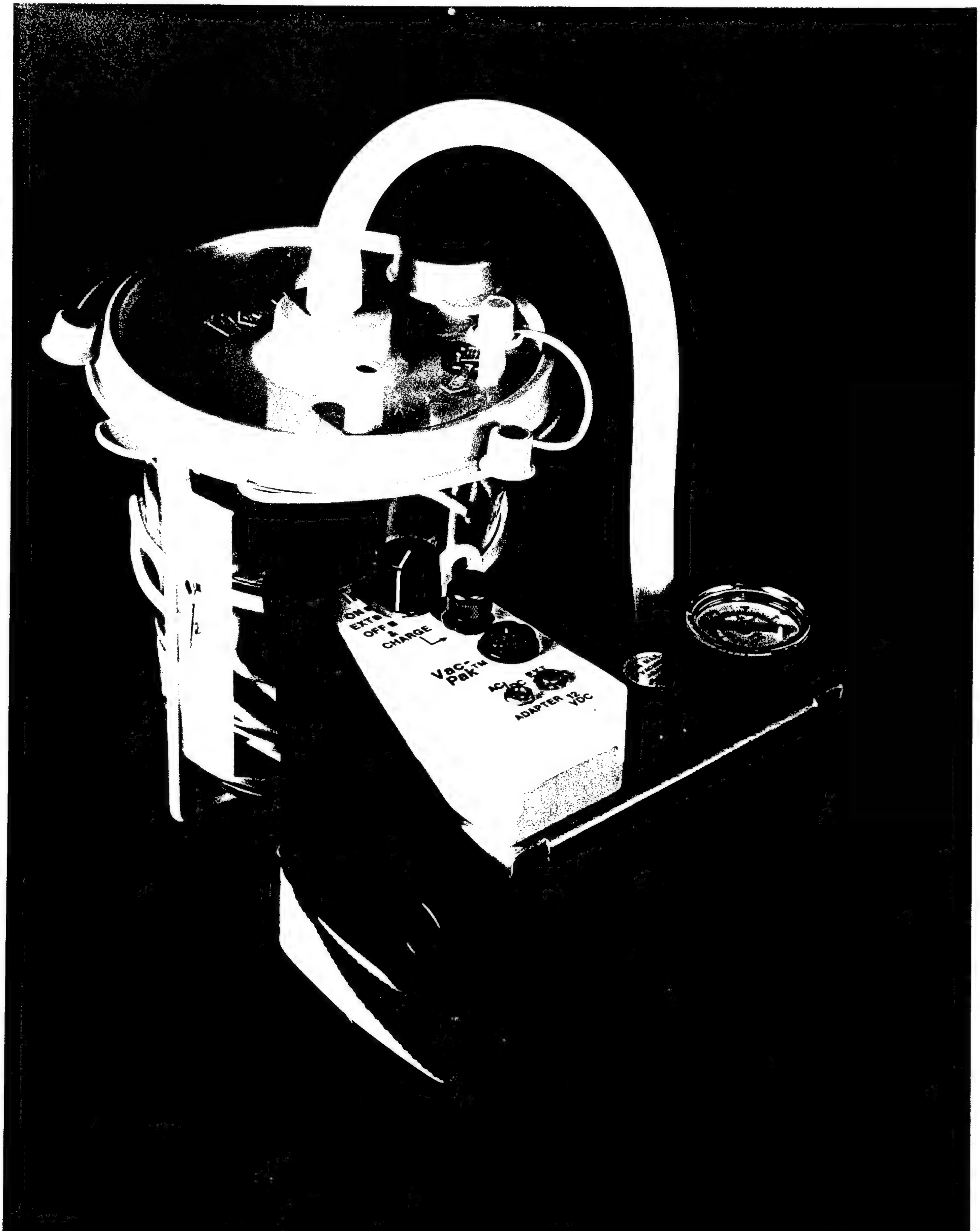

FIG 2

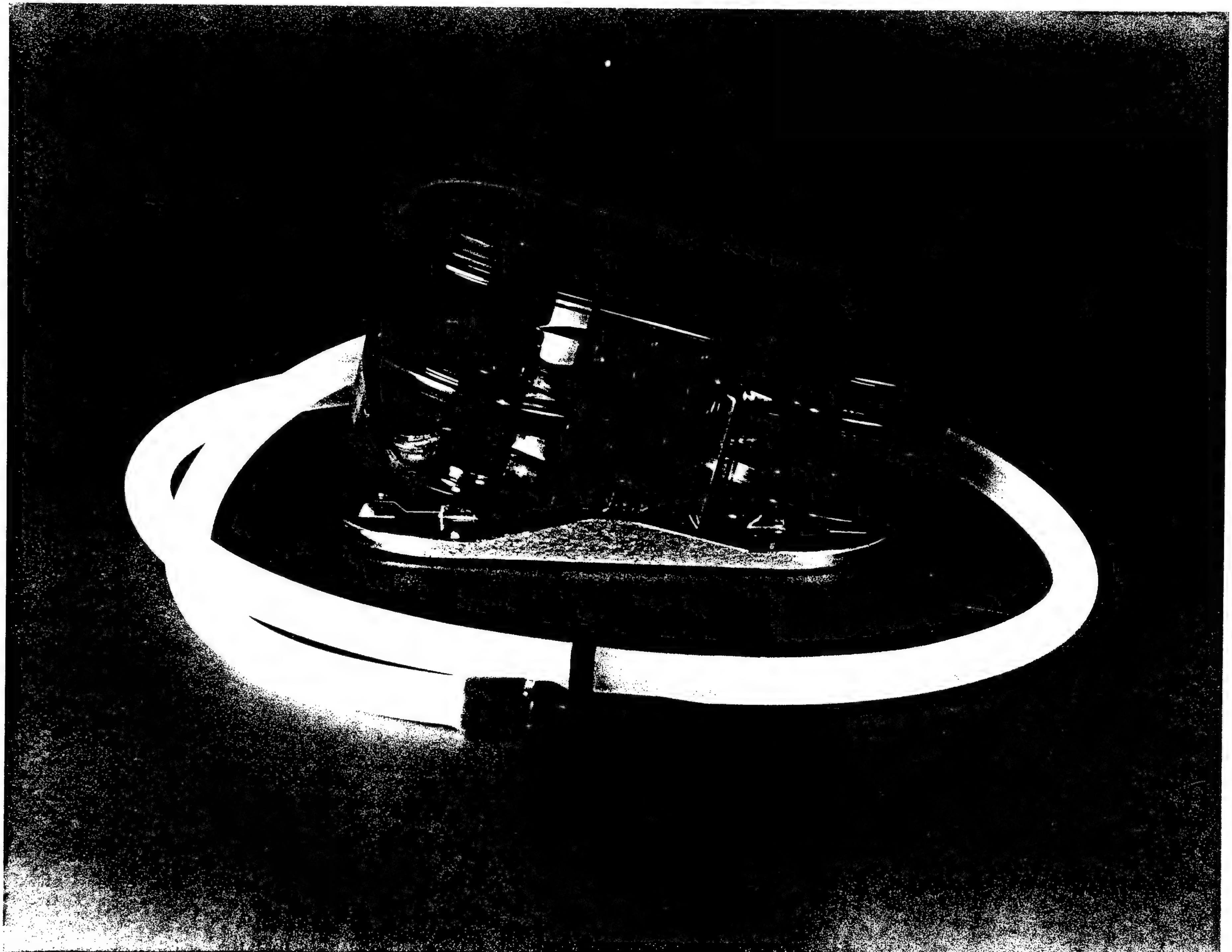

FIG 3

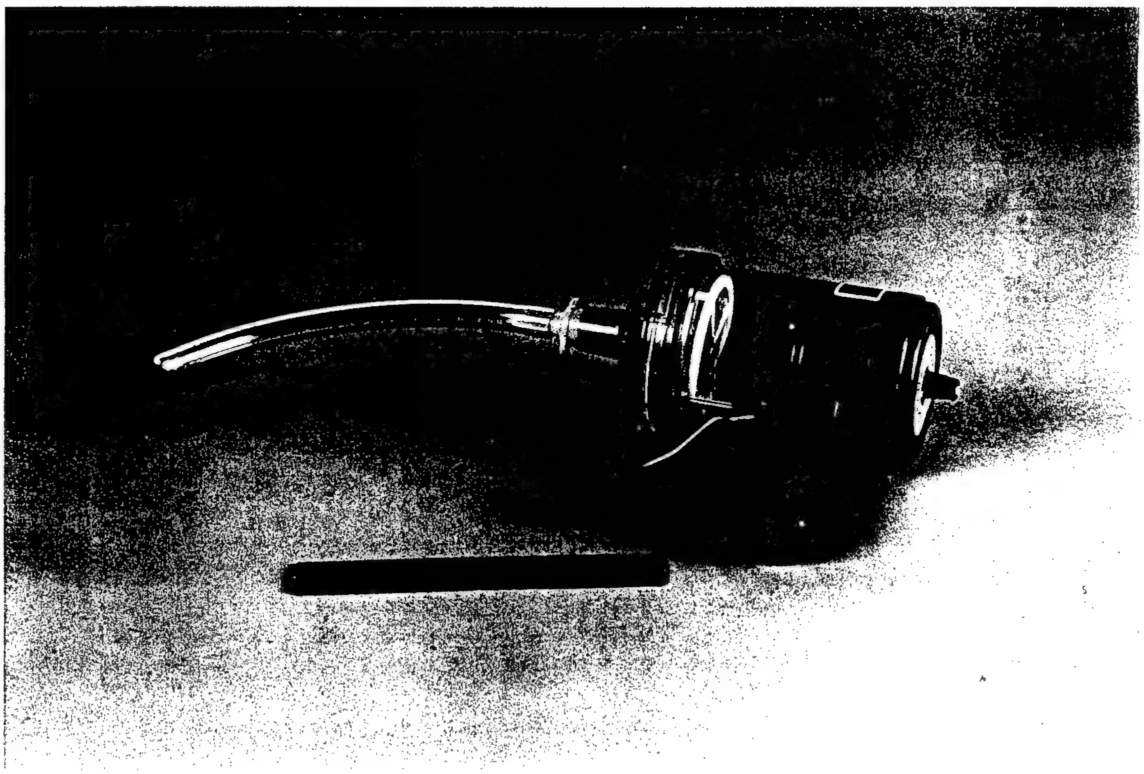

Figure 4: Vitalograph Emergency Aspirator
(with attached wide-bore suction catheter)

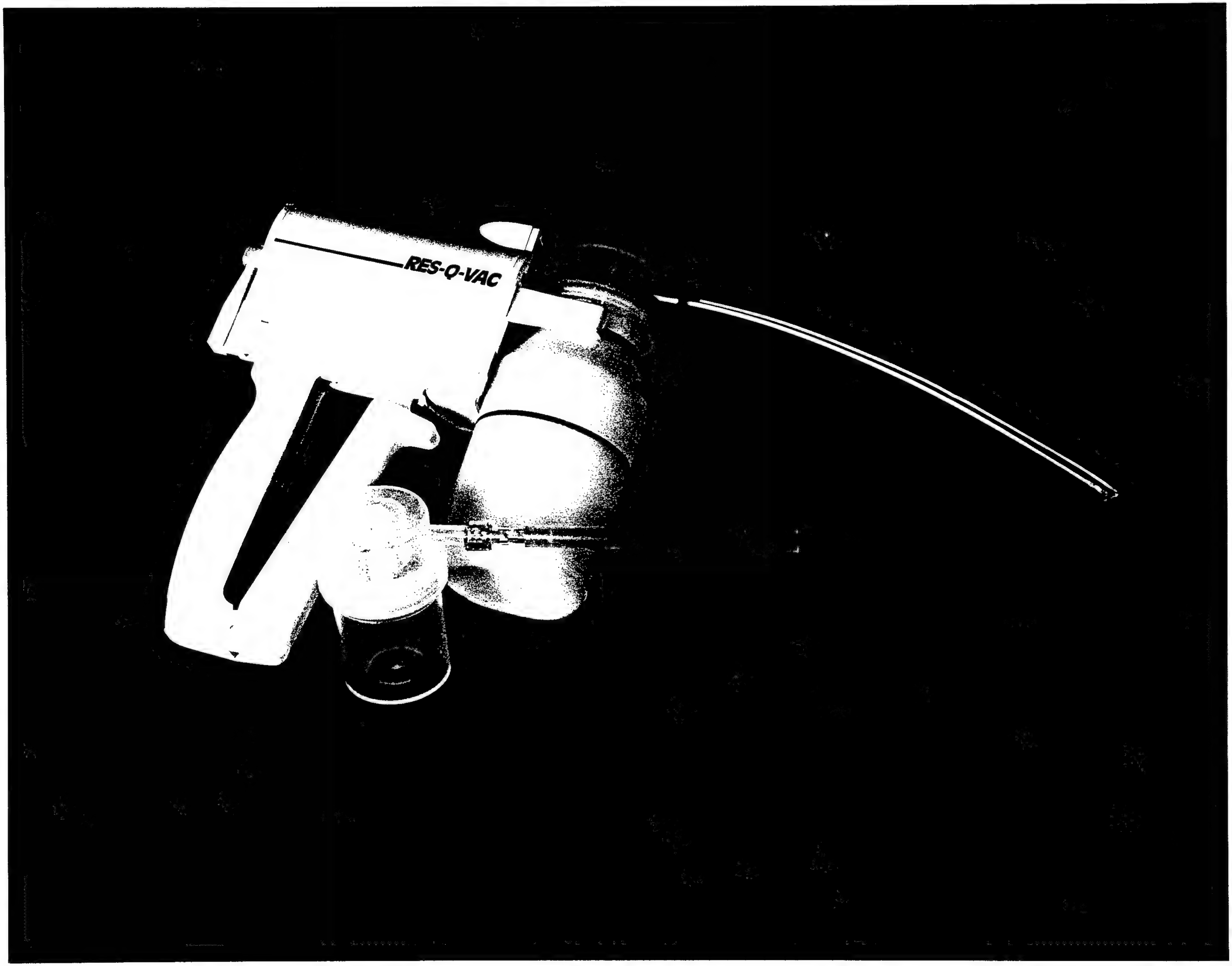

FIG 5

Fig 6

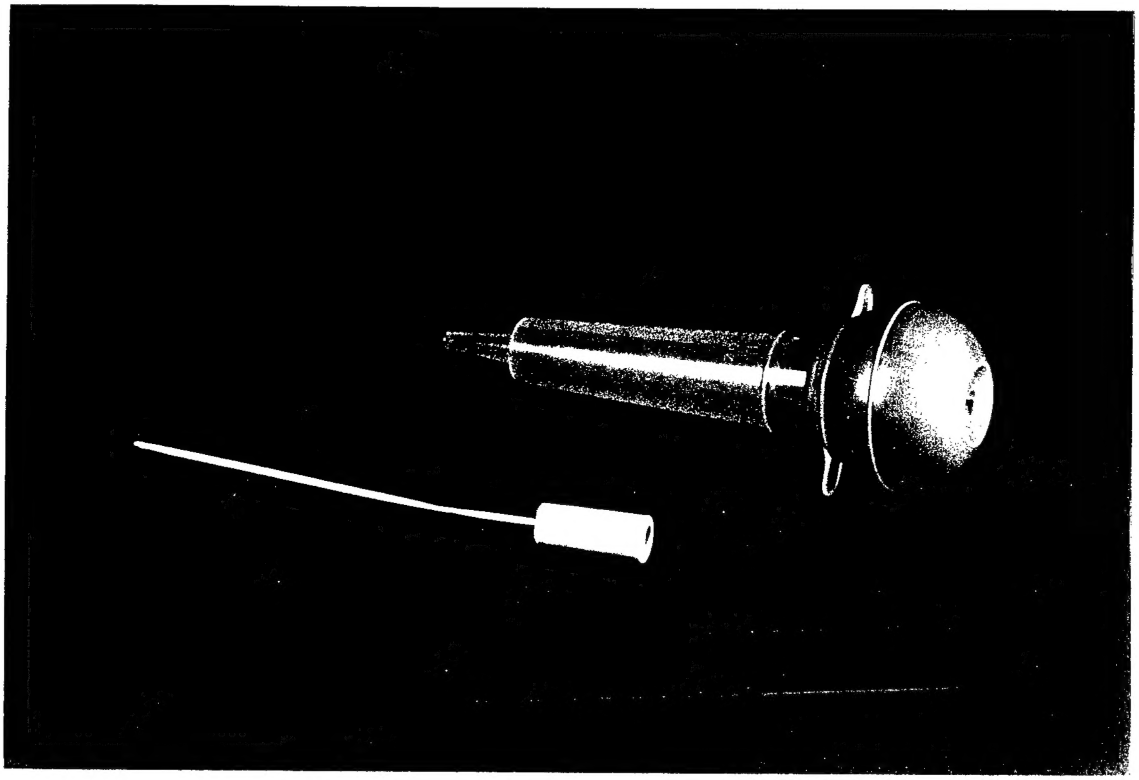

Figure 7: Bulb Syringe and attachable wide bore suction catheter

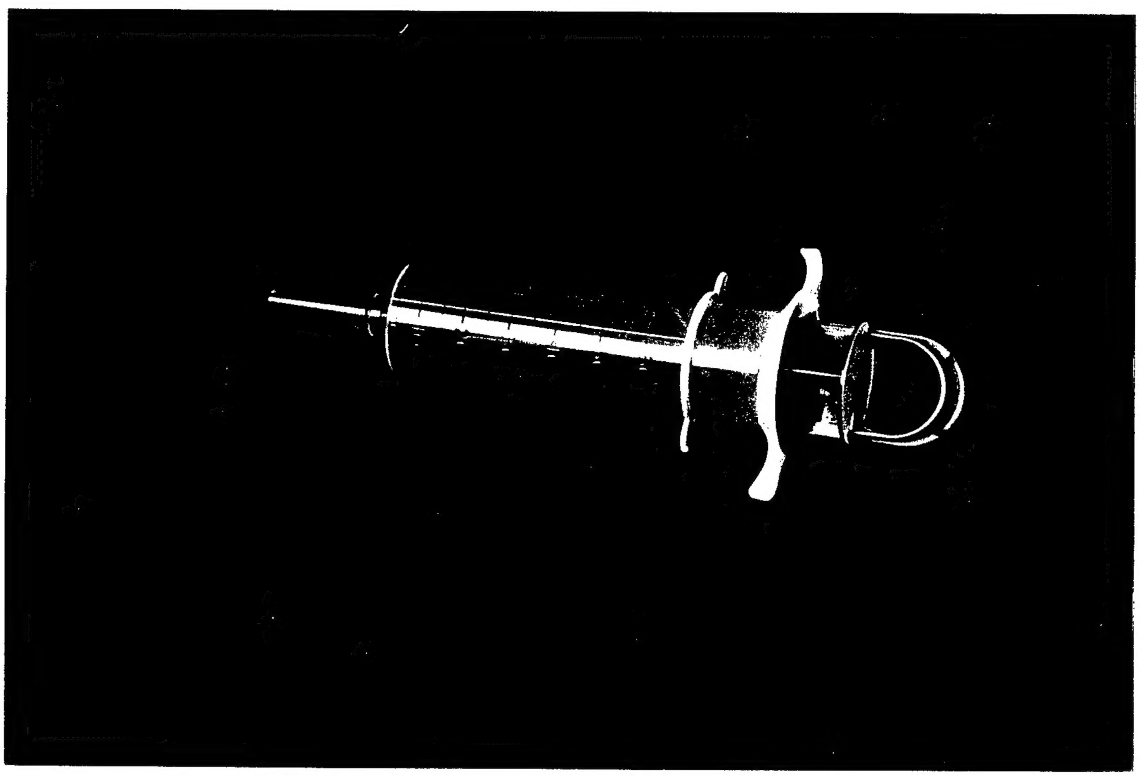

Figure 8: Toomey Tapered-Tip Plunger Syringe

	POWER	DIMENSIONS L" X W" X H"	WEIGHT (GRAMS)	VOLUME (CC)	VACUUM 1ST PUMP (MM HG)	VACUUM MAX (MM HG)	APPROXIMATE COST
Impact VacPakII Ultra-lite	Battery	9" x 6 1/2" x 8"	2779	1200	Gradual rate of rise to max	516	$450
Laerdal Compact Suction Unit	Battery	6 1/2" x 6 1/8" x 6 1/4"	1744	1000	Gradual rate of rise to max	508	$500
Ambu Twin Pump	Foot	8 1/8" x 4 1/4" x 4"	1076	600	149	612	$300
Repro-Med Res-Q-Vac	Hand	7 1/2" x 2" x 7"	222 adult 190 pediatric	218	96	414	$50 for kit of 1 handle and 1 cartridge ($12/replacement cartridge)
Vitalograph Emergency Aspirator	Hand	6 3/4" x 3 1/2" x 6 1/2"	376	240 (unlimited)	87	479	$200
Laerdal V-Vac	Hand	14 5/8" x 2 1/8" x 4 5/8" together 10 1/4" x 3" x 4 5/8" pieces side by side	291	400 (unlimited)	237	237	$75 for kit of 1 handle and 2 cartridges ($12/replacement cartridge)

TABLE 1

TABLE 2

Suction Pump Evaluations
Questionnaire

Do you presently take a suction device into the field? YES NO

If you do, which device do you use? ____________________

Why do you use that particular device?

Place an "x" in the appropriate column.

unimportant very important

	1	2	3	4	5	6	7	8	9	10
How important is size?										
How important is weight?										
How important is suction power?										
How important is the noise factor?										
How important is the ability to have electrical power?										
How important is it to have adapters for tracheal suction?										

Please rank the above from most important (1) to least important (6).

size _____ suction power _____ electric power _____
weight _____ noise _____ adapters _____

Are there any other factors which should be considered? YES NO

If so, what other factors would you say are important? How would you rank them?

Which device do you think overall met the majority of your goals? Why?

Which device did you like the least? Why?

Please rank the devices evaluated from best (1) to worst (4).

Laerdal Compact Suction Unit	_____	Repro Res-Q-Vac hand pump	_____
Ambu Twin Pump-foot powered	_____	Laerdal V-vac hand pump	_____

What suggestions do you have for possible modifications?

Do you find sessions with medical research developers helpful? Please make suggestions for improvement.